Mapping Lunar Lander Plume Ejecta Trajectories to Lunar Surface Elevations

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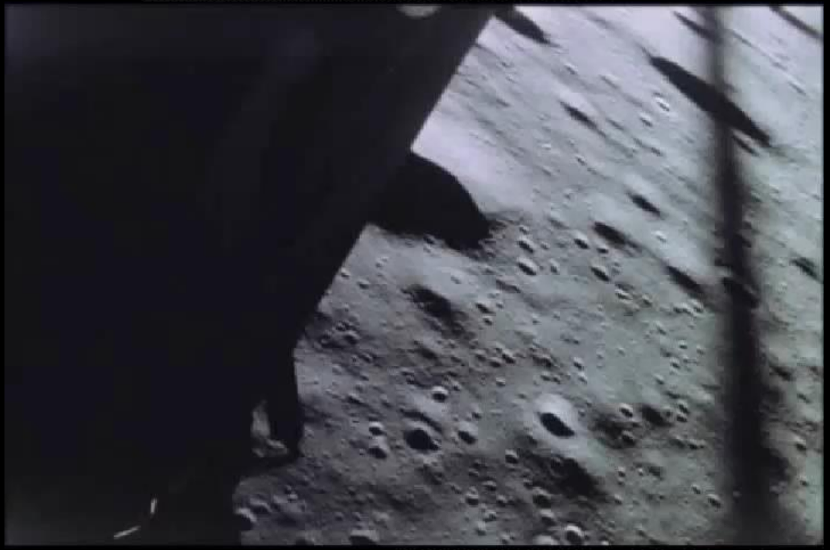
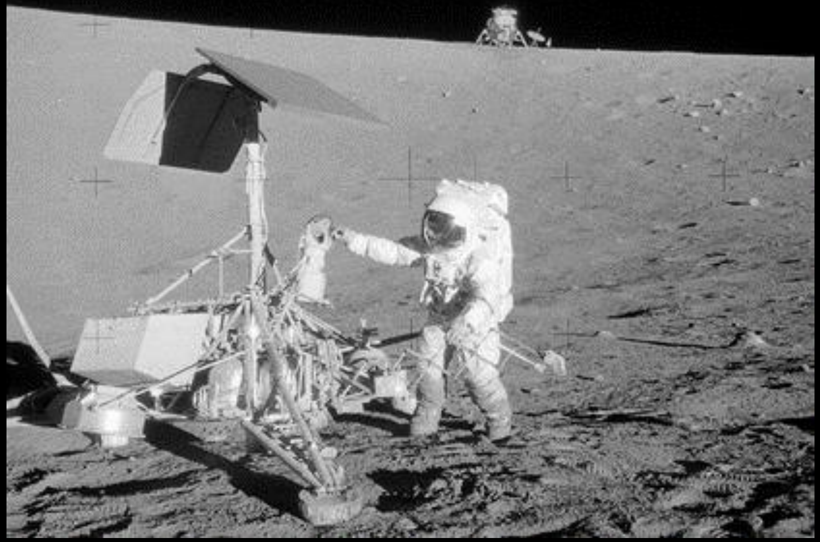
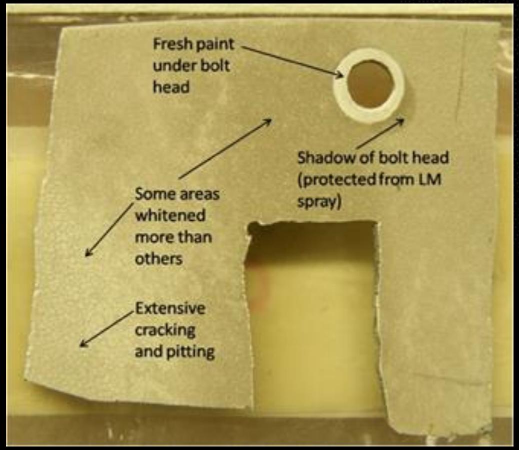
Plume Surface Interaction Ejecta Risks

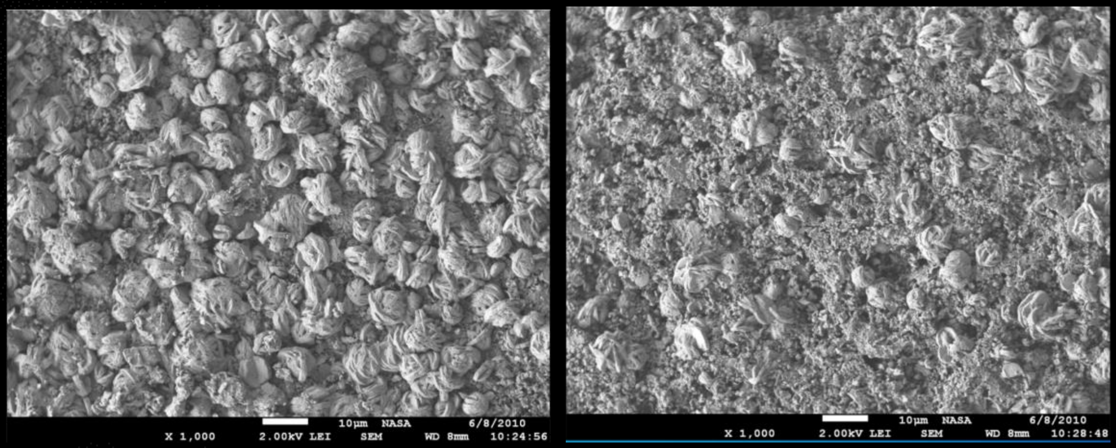
- Lessons learned from Apollo 12 & Surveyor 3.
- Ejecta particles are a risk to surface systems and areas of interest.
- Where and when will ejecta impact the surface?
- What are the initial angles and velocities?
- There is a broad range of estimates, currently.







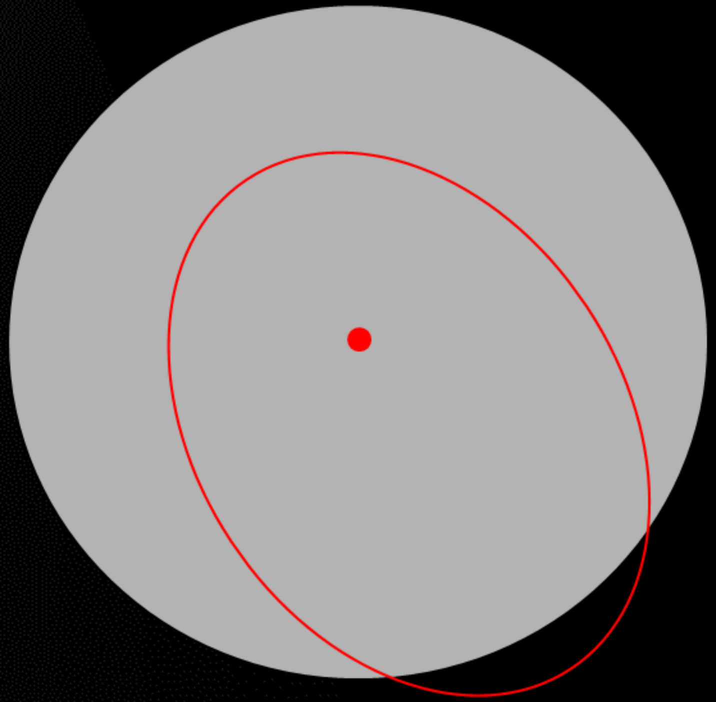
Credit: NASA/UCF

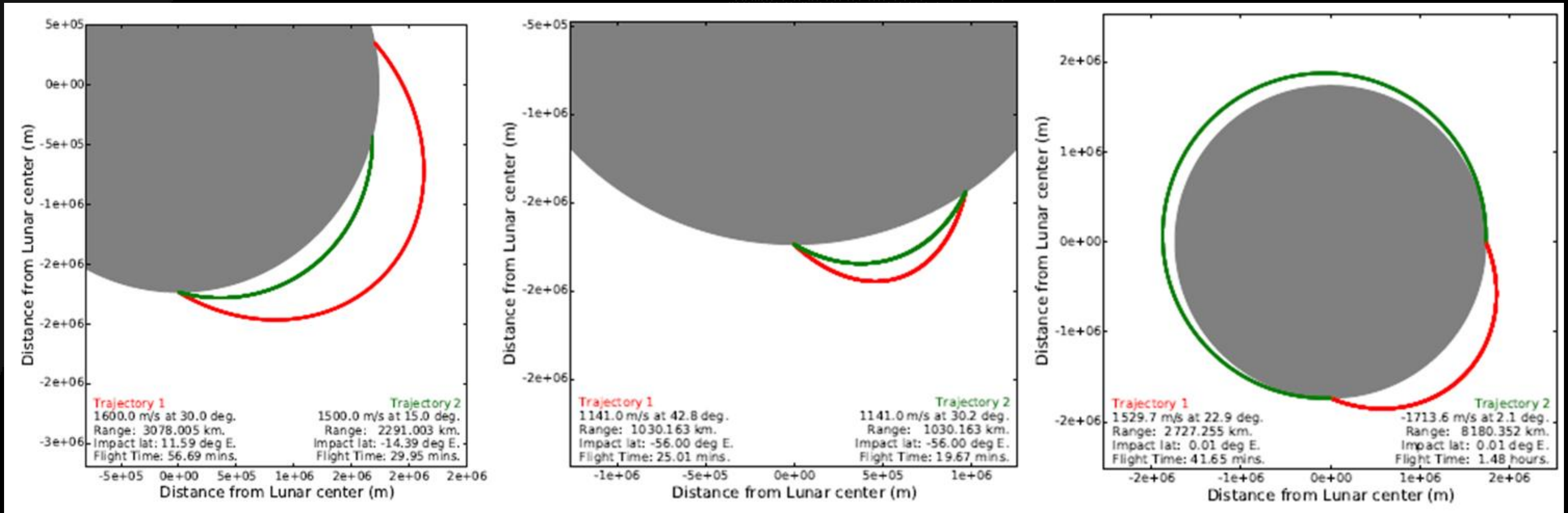


1000x SEM images [left] Undamaged paint. [right] Damaged paint.

Ejecta Dynamics

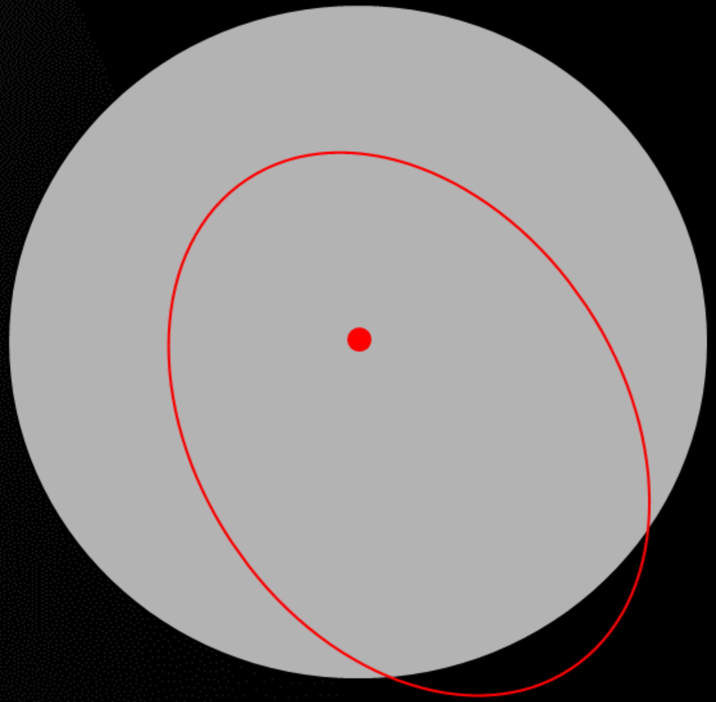
- Conserve E and p for eccentricity.
  - Similar approach to Shipley et al. (2014) & Bernardoni et al. (2019).
- Apoapsis gives max height.
- Solve for origin and impact points at R_m to get range and latitude.

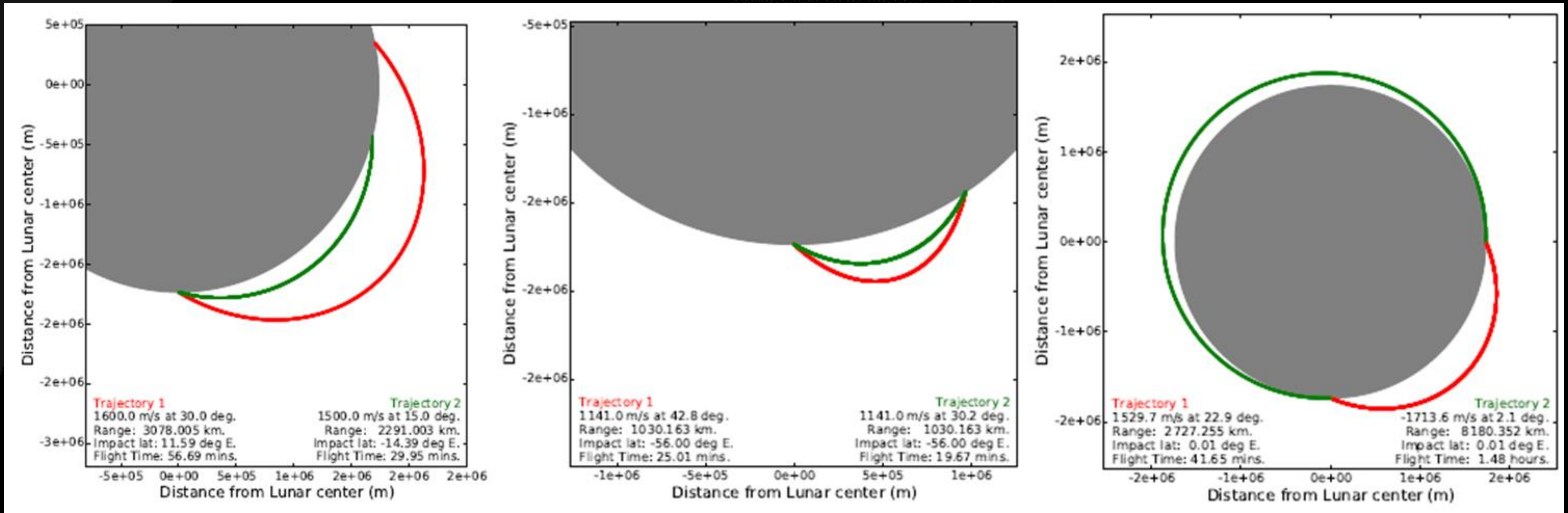




Ejecta Dynamics

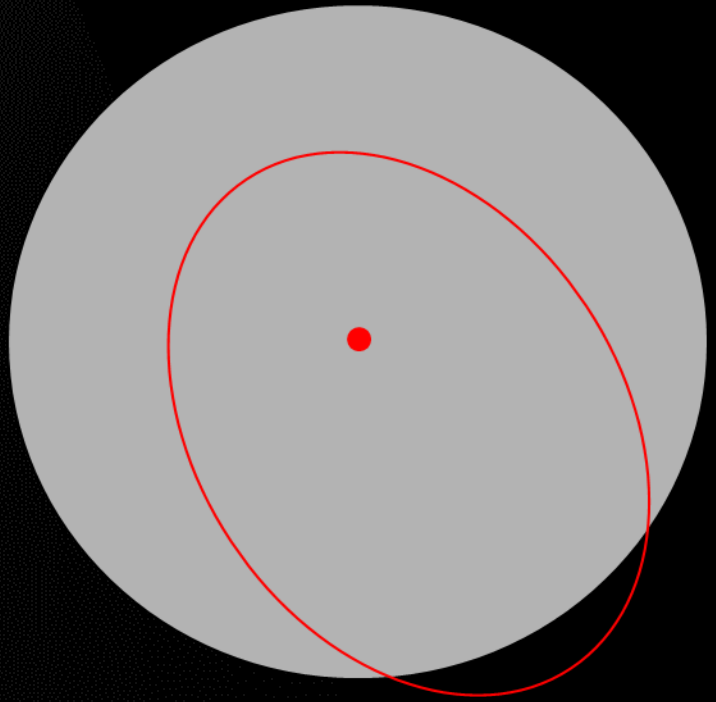
- Mean anomaly and time since periapsis determines time of flight.
- Rotate argument of periapsis to define a specific origin lat/long.

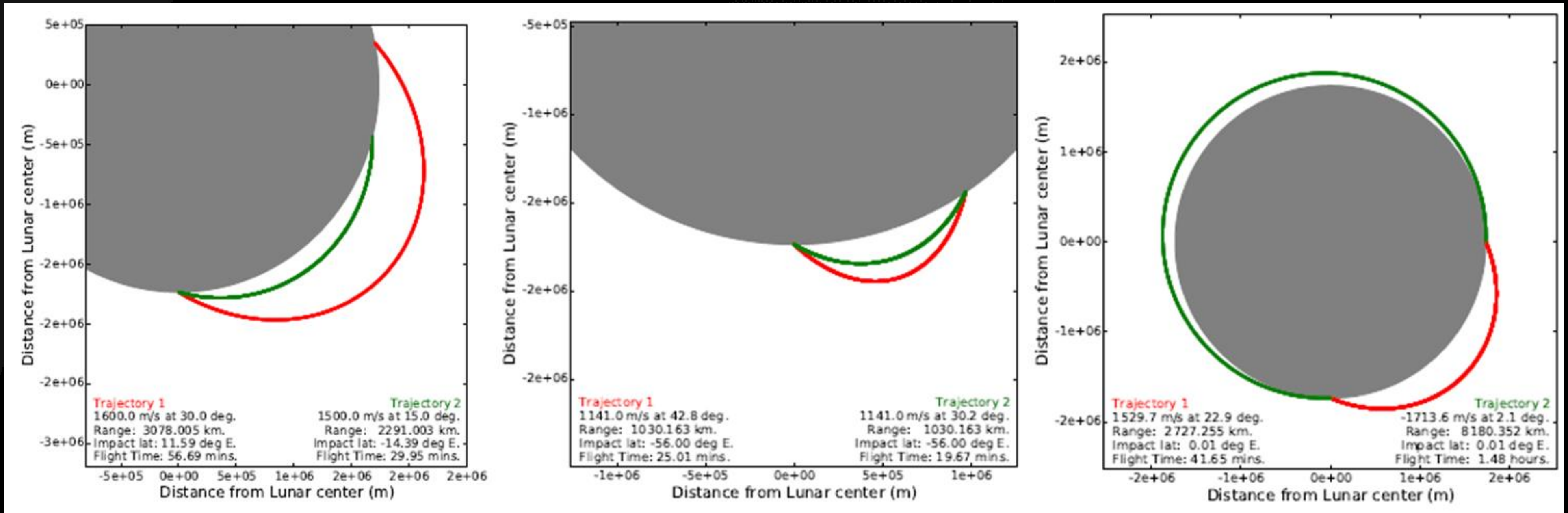




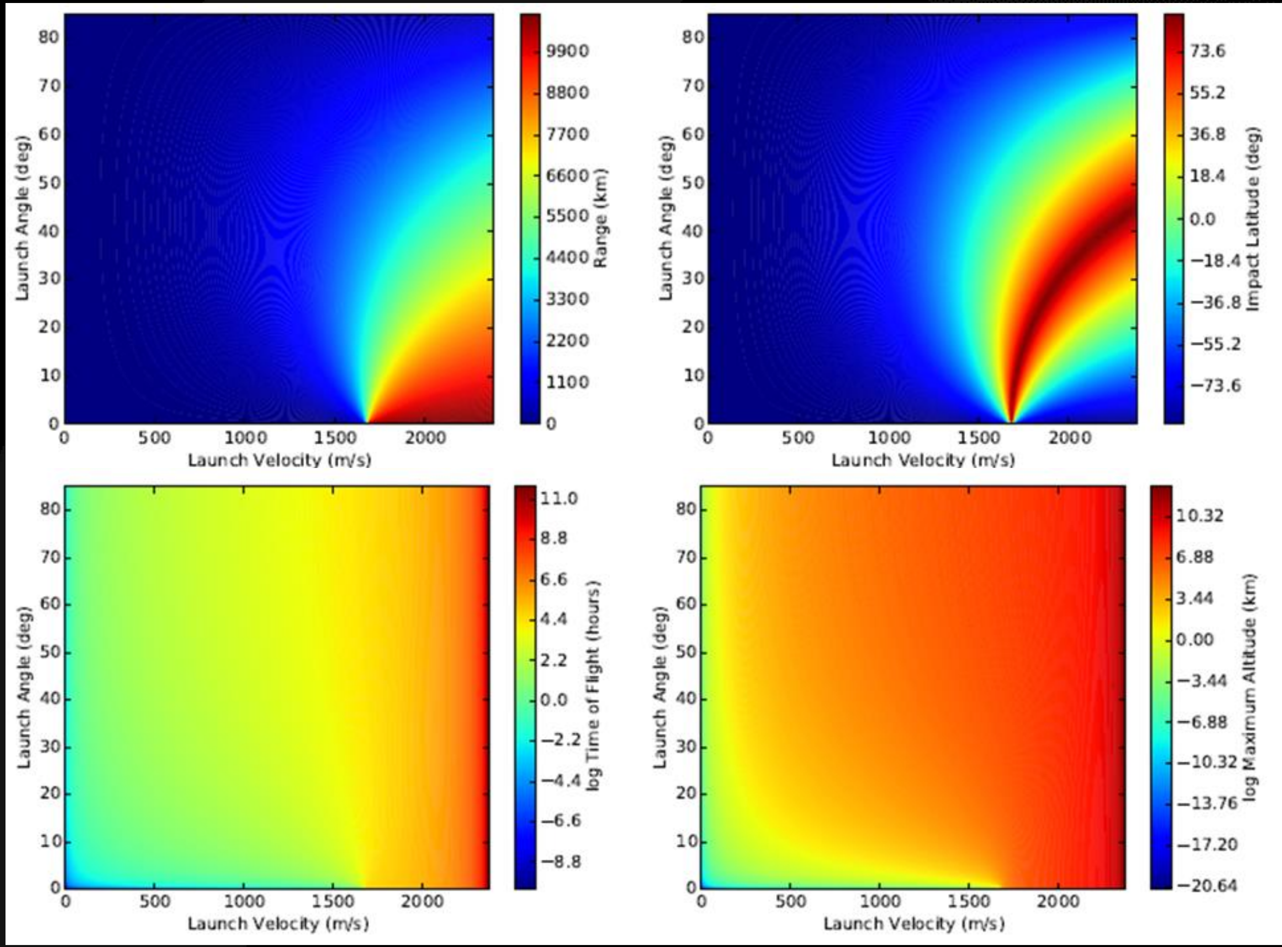
Ejecta Dynamics

- Coriolis largely negligible for:
  - Short times of flight.
  - South pole origin.
  - Azimuthally isotropic ejecta flows.

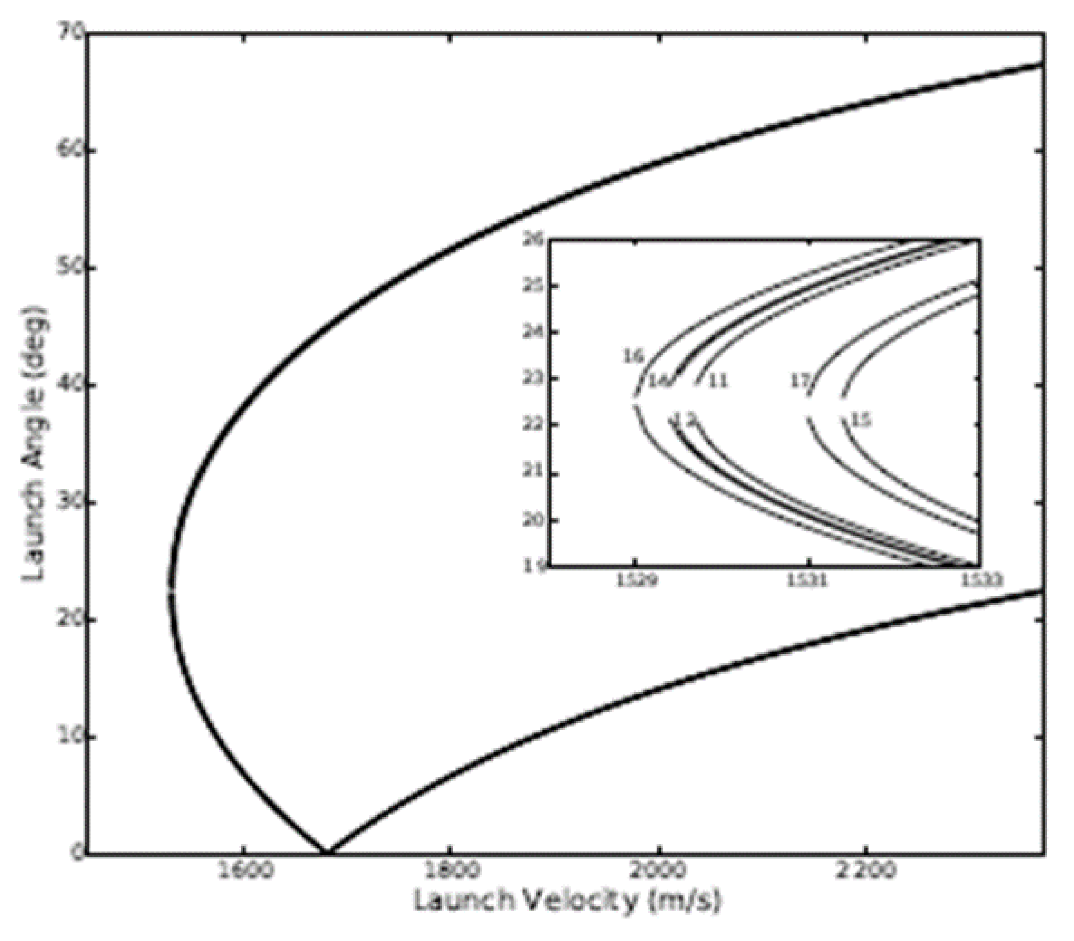




Ejecta Dynamics



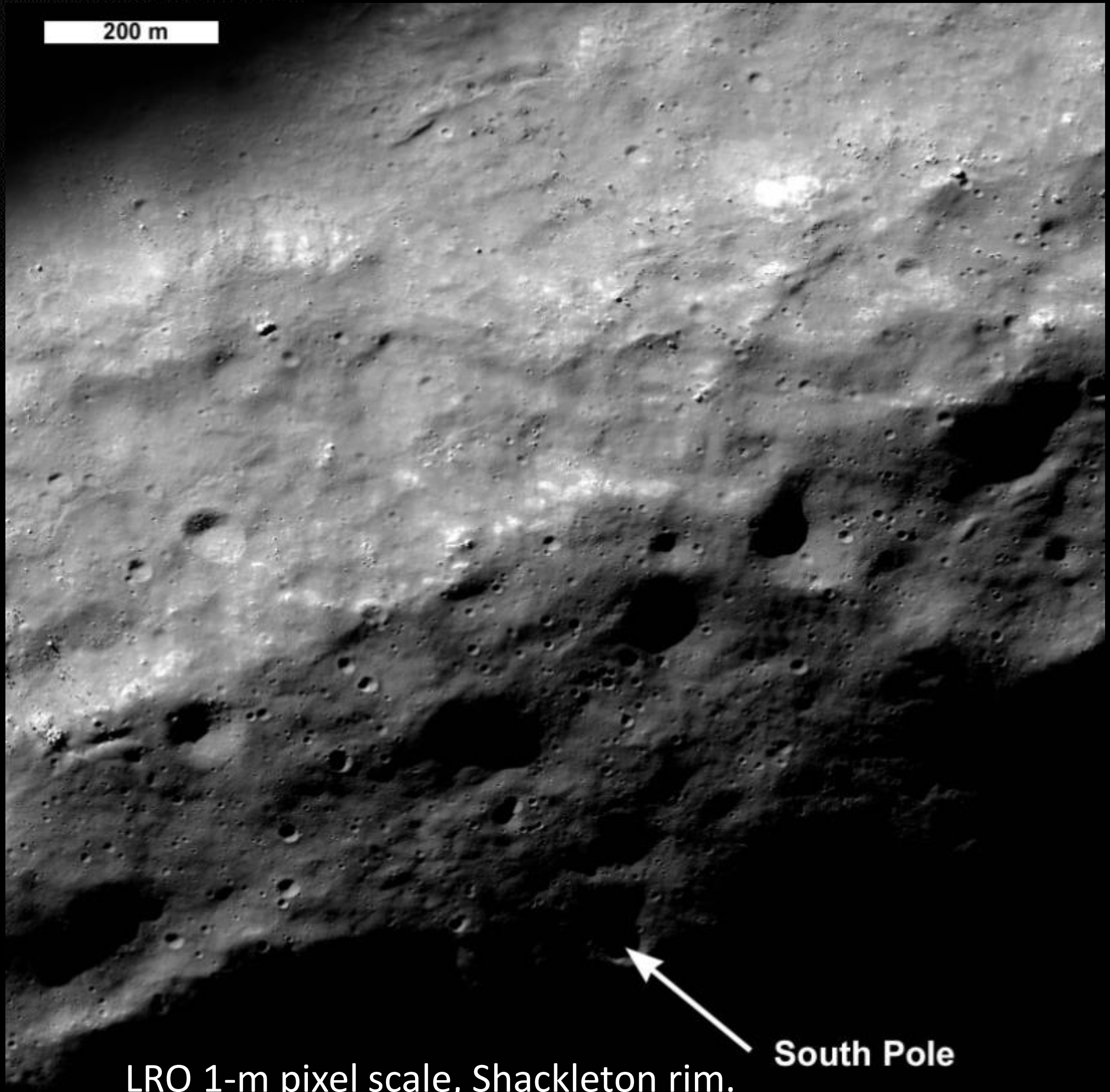
Range, location, TOF, Max altitude.



Conditions to impact Apollo sites.

Ejecta Mitigation

- Landing module design:
  - Nozzle locations/actions.
  - Descent profile.
- Artificial:
  - Landing pads.
  - Berms.
- Natural:
  - Topography.
  - Sun angle.
- Combination.
- Interesting trade space.



LRO 1-m pixel scale, Shackleton rim.

Ejecta Trajectory Terrain Mapping

- Use the LRO DEMs.
- Choose Lat/long.
- Azimuthal steps chosen for profile extraction.

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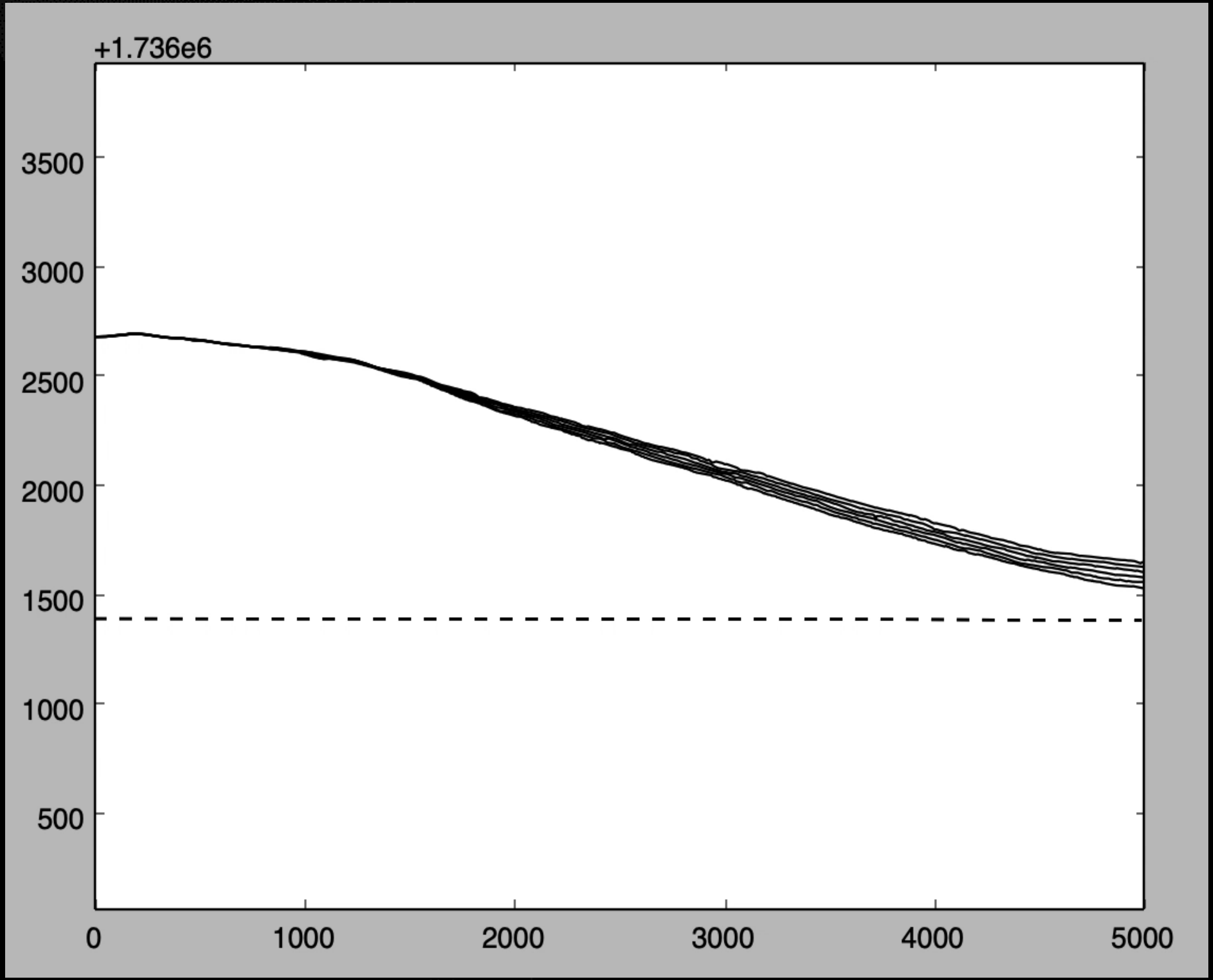
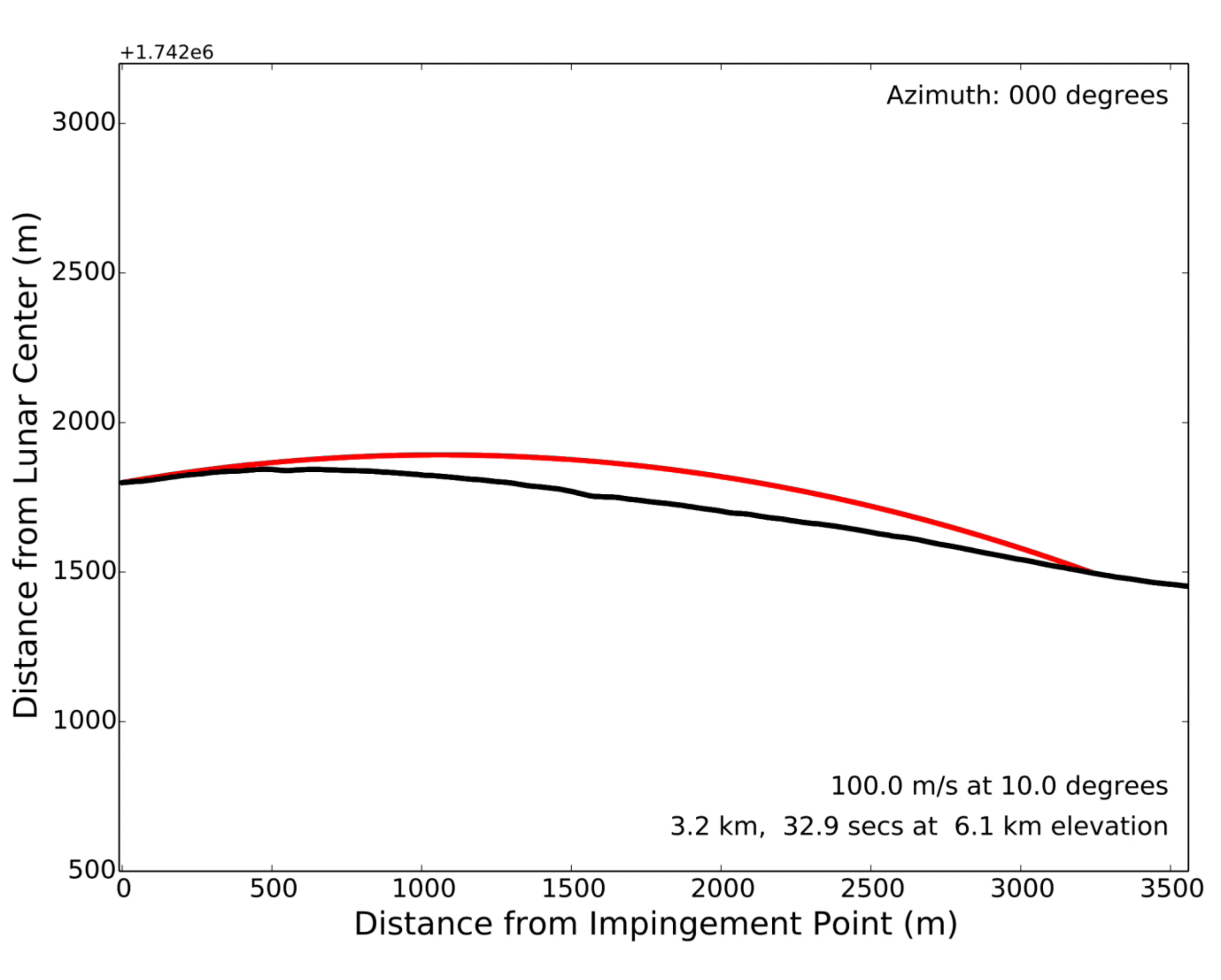


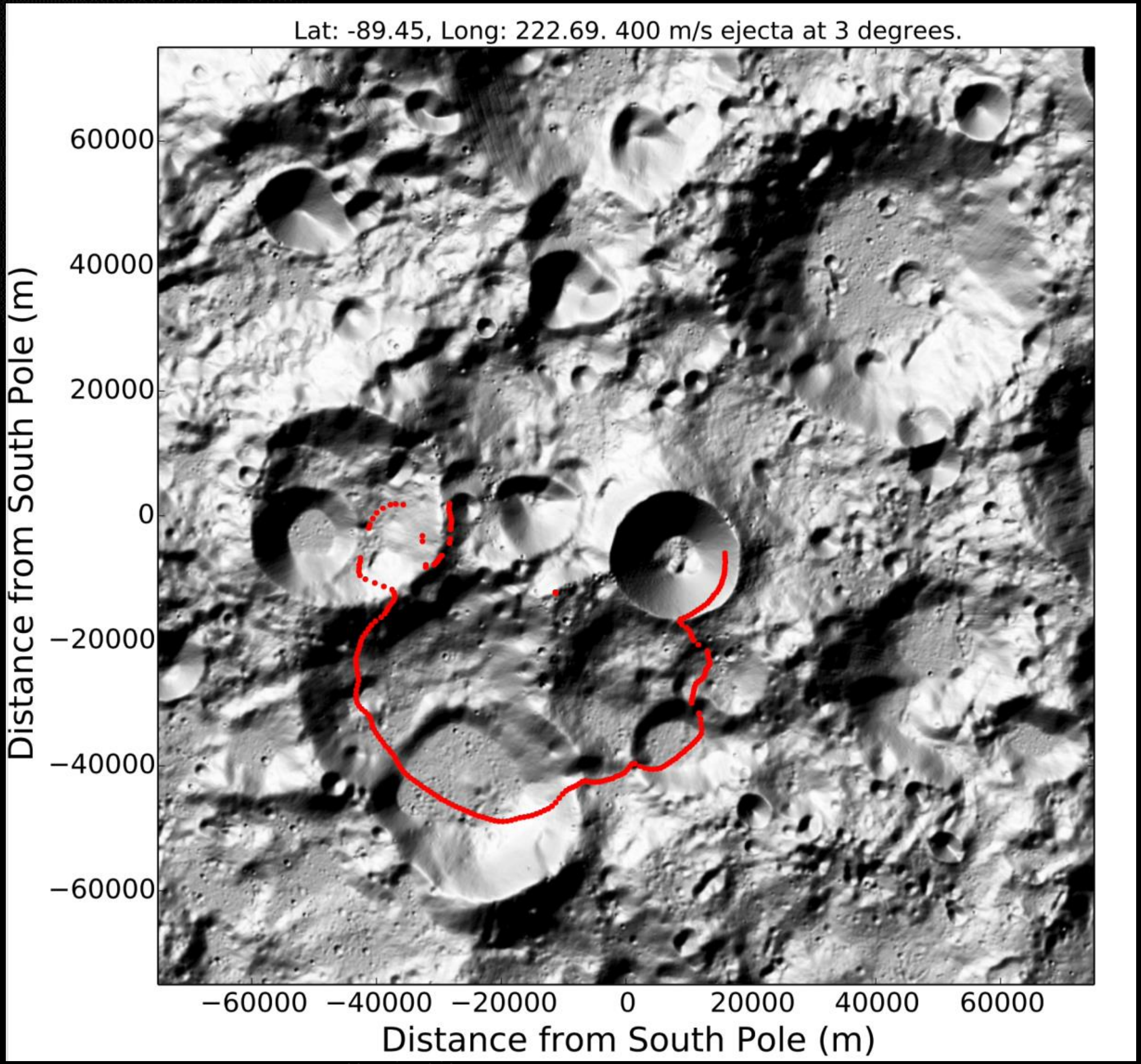
Ejecta Trajectory Terrain Mapping

- Use the LRO DEMs.
- Choose Lat/long.
- Azimuthal steps chosen for profile extraction.
- Extract terrain profiles.
- Match trajectories to terrain profiles.
- Update range and time of flight.

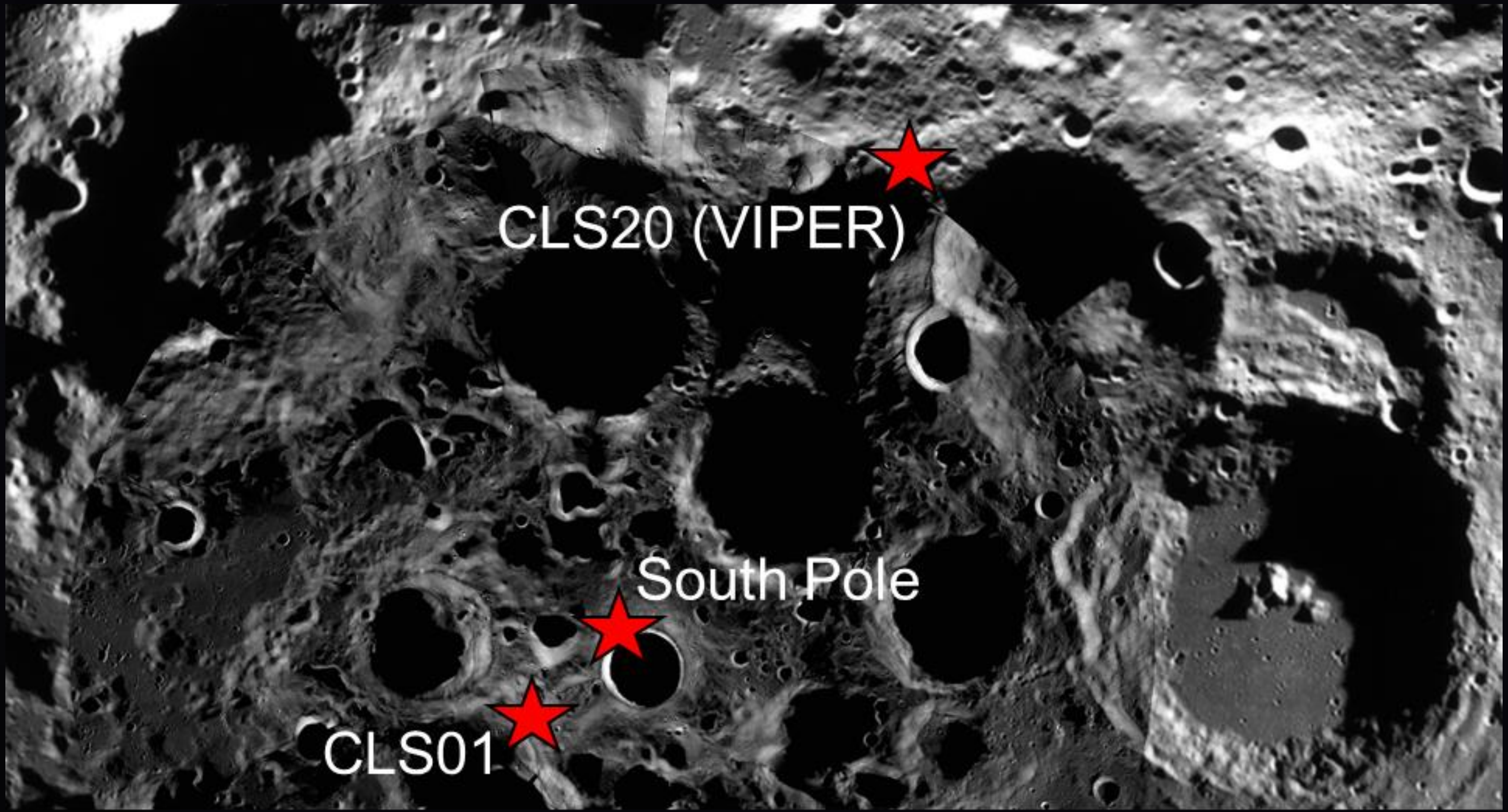


Ejecta Trajectory Terrain Mapping

- Use the LRO DEMs.
- Choose Lat/long.
- Azimuthal steps chosen for profile extraction.
- Extract terrain profiles.
- Match trajectories to terrain profiles.
- Update range and time of flight.
- Map azimuths back to DEM.



Ejecta Rings Around any Given Landing Site



Summary

- Plume-surface interaction ejecta pose a risk to sustained lunar exploration.
  - Lunar operations, ISRU, scientific studies, historical sites.
- Risk assessments require knowledge of ejecta velocities, but no direct measures yet.
- Parameter space can be populated to determine which ejecta velocities are high risk for impact locations.
- Terrain plays a major role in trajectory mitigation and should be considered at candidate landing sites.
- Coriolis is negligible for lunar pole origins and short times of flight.